Special Issue On: The Breakthroughs in Additive manufacturing (3D Printing), Space Entrepreneurship and Advanced Battery Technology as Challenges to Actor-Network Theory

Title: Innovation and technical transformations in living technology: An entanglement of agentised matter, ANT and natural computing.

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Abstract

This essay proposes that we are in the midst of a cultural shift from the Industrial Age to an Ecological Era, which demands that we re-conceptualize the world and operate within it differently. It discusses the opportunities raised by Actor Network Theory (ANT) in helping us navigate the transition from an object-centred view of reality, towards one that also engages with process-oriented concepts. In particular, the impact of the convergence of these worldviews on technological innovation is explored through recognising a different material framework that engages with nonlinear systems. ANT offers a unique opportunity to deal with matter at far from equilibrium through the notion of assemblages, which act as a new kind of operating system that behaves in remarkably lifelike ways. Empirical evidence is provided for such an ANT-based, production platform through laboratory findings in an emerging field of computation called 'natural' computing. A range of models and prototypes are discussed. The resultant lifelike technologies require unique infrastructures that facilitate the movement of elemental fabrics (earth, air, heat, water, plasma). While much evidence for their existence is propositional and qualitative, as they are in their earliest stages of development, these lifelike technologies have the potential to radically alter the impact of human development and transform it from being harmful to beneficial to the environment.
(Words 163)

Key Words: lifelike, assemblage, living technology, natural computing, bioprocesses

Introduction

I recommend the paper to be supplied with some illustrations. It will only benefit if the author include into the text a limited number of visual/graphic materials that will facilitated the reader in better understanding some of the arguments [Bütschli experiments and some drawings of ecological technologies – perhaps Arup, seek permissions].

I strongly recommend the author to introduce a short paragraph (possibly in the beginning of the paper), where she/he make more explicit her/his own positions and the objectives of the paper.

This paper positions the role of ANT as forming a context in which new forms of technological innovation can emerge that are qualitatively different than machines. As such, ANT offers a critical framework for facilitating radical breaks with the developmental platforms that have characterised human civilization to date.

We are at the breaking wave of a paradigm shift in how we live as we transition from an Industrial Age to an Ecological Era. For the first time in a couple of millennia, the general populace of Western civilization has embraced the idea that reality is in a state of constant flux. While much debate exists within academic circles, the impacts of these practices are not simply for an educated elite but impact on a wider society. This perspective has been catalysed by the explosive impact of the Internet and is more than an attitude - but a game-changing in the way we view the world. It affects every aspect of our lives from the way we live to how we solve problems. Yet, we're suffering a kind of disorientation as on an everyday basis, our thoughts and actions slip between different models of experience, like fish that don't know we're wet. On the one hand most of us are steeped in the classical Western traditions and tools of atomism, Enlightenment and modernity – while we have also become fully engaged with the Pandora's box of process and systems that characterize a Heraclitean reality. In the last thirty years this has slipped around us through our online encounters, in the phenomenon of globalization and by virtue of our increasingly turbulent weather patterns. Let me be clear, this is not simply about replacing one hegemony with another, but implies our deep immersion in simultaneous realities, where experiences are compound being forged through converging fields of interaction that simultaneously obfuscate, create and delight.

This cultural transition may be thought of as an Ecological Era because of its allegiance with a set of concepts that have been gathering momentum across many different knowledge fields, especially in the last hundred years - across disciplines as diverse as philosophy, cybernetics, ecology, holism, philosophy, mathematics (Gleick, 1997), cultural theory and neuroscience – and have already begun to shape our attitudes. In fact, making a transition towards the Ecological Era is only in part a voluntary decision. It is of no consequence that you prefer a minimalist efficient aesthetic to a naturalistic one. It has very little to do with whether you actually 'believe' in climate change, pride yourself on green citizenship or recycle your trash. Rather the Ecological Era is borne from our complete immersion within a restless system of change for which we are not yet fully equipped. This often leaves us feeling that we're constantly being asked to nail jellies to walls as we periodically ponder some of the inevitable discontinuities within a process of change.

Look around you and you won't see the Ecological Era directly - but you may observe its symptoms. Perhaps you'll notice solar panels on a south-facing roof, recycling bins tucked behind the parking lots at a supermarket, which vacuum packs its products in 'biodegradable' plastics. Maybe you'll glimpse a headline on your smartphone that more carbon dioxide is pouring into the atmosphere than ever before as a car revs its engine while you wait to cross at the traffic lights, spewing more greenhouse gas into the air. Yet, when you look up, you wonder how this invisible gas relates to the crisscross of plane trails and the barely perceptible geostationary satellite networks and space junk that litter the sky. Perhaps you'll pull your coat around you tightly as for no apparent reason the wind has picked up and head for shelter in a fair-trade coffee shop and feeling warmer, try to figure out how much of your life is informed by scientific fact, urban myths and old habits. Understandably, you may begin to wonder what on earth our contemporary culture is all 'about'.

However, if this transition is to be more than cultural purgatory - where it is simply a matter of time before our dominant object-centred worldviews re-group and re-present their established reality using a new set of arguments, which has been our strategy for the last two thousand years - then the context in which these changes are being played out needs to change. In other words, we need a conceptual and practical toolset that enables us to act upon, experiment with and implement the consequences of new ways of seeing. In short, a new technological platform is needed if we are truly going to seize the opportunities provided by being able to imagine the world in different ways - so that we can increase the range of options through which we can construct new futures.

ANT is ideally placed to assist this process with Promethean potential for us to enter into a new, age of discovery. It offers a unique framework for technological innovation by creating a set of contexts through which the untapped potential of matter at far from equilibrium states can be unleashed and brought into proximity with classical forms of making.

The science of systems

Digital natives are quite comfortable in a world in dynamic flux, where they can transgress formerly impenetrable boundaries of identity, geography, politics and disciplines. Everyday experience itself has become fluid and impermanent. Such a fickle state of affairs not only demands its own set of concepts but also requires technical avatars that can navigate complex and unpredictable terrains. These are not best served by classical Western systems of thought.

Yet, general systems theory has already stepped up to the scientific task of making sense of unstable realities by outlining the principles of organization that underpin complex dynamic elements, which are open to and interact with their environments (Von Bertalanffy, 1950). These complex systems are self-regulating, can acquire qualitatively new properties through emergence and are therefore in a state of continual evolution. With this change in perspective a new approach to design and engineering has been possible that can deal with uncertainty and express probabilistic outcomes. Over the course of the 20th century, the engineering principles of general systems theory have evolved through the field of cybernetics (Wiener, 1948) and have been characterized by distinct phases of development, underpinned by Claude Shannon's theory of information (Shannon, 1948). Cybernetics includes the study of homeostasis (maintaining steady states in fickle environments), reflexivity (entanglement between internal and external changes in the system) and virtuality (digital patterning) (Hayles, 1999).

The new opportunity presented to digital natives however, is in the relationship between cybernetics and recent biotechnological developments, where the processes of life and the material systems that embody them can be regarded as technical platforms. Such opportunities were not available to the cyberneticists despite the intriguing experiments conducted by Gordon Pask and Stafford Beer, who were the first to experiment with the technical qualities of agentised material substrates in cybernetic systems. Pask (Bird and Di Paolo, 2008, p185-212) explored crystal formation in response to street sounds and Beer (Beer, 1994) used the microorganism daphnia – a microscopic crustacean commonly known as the 'water flea' - and entire pond ecologies as alternative media for cybernetic systems. However, their ability to manipulate these systems became quite limited from a design and engineering context, since the emerging field of biotechnology was not mature as a technical platform and largely inaccessible to cross-disciplinary collaboration.

Despite these limitations our machines have nontheless become "*increasingly lively*" (Haraway, 1985), and have even reached the status of "*living technology*" – by possessing some of the properties of living things without being granted the full status of being truly 'alive' (Bedau, 2009). Such advances warrant new approaches to develop the scaffolding for a life-promoting, forward-looking approach towards emerging technical systems, which may shape how we work, live and even alter our environmental impact.

To seize the opportunity to re-order the structures of thought and practice that characterize living systems, the actor-nets of ANT need to be mobilized and become more than just a 'description' of possible relationships (Latour, 2005) but to take a more active stand in promoting the emerging 'new reality', an engagement with far from equilibrium materials (which characterize living systems) and lifelike technologies. One of the ways ANT can do this is by helping synchronize new cultural and material realities that are apprehended by these emerging technical platforms. Specifically, ANT can connect the multiplicity of heterogeneous events that facilitate life's processes. Moreover, its operational framework transcends inevitable relationships between people implicit in the development of new production systems – but also include other living agencies – from bacteria, to forests, soils, air and oceans. It also provides a means through which the context and materiality of spaces that promote lifelike events may be evaluated, which allows us to establish new rule sets about how we collectively inhabit them.

By providing a set of concepts that can link formerly discontinuous concepts and bodies, ANT can provide clarity as an avatar in the midst of consternation about living technologies. While it has no master plan, it asks us to reconsider our values at this uncertain time, so that we can create new futures for ourselves and make ecological – not carbon – footprints as our legacy for next generations.

The nature of 21st century matter

At the start of the third millennium, the nature of the material realm appears to have altered. Far from being the obedient, brute, homogenous substances that characterized the 'standing reserves' (Heidegger, 1993) of matter chewed upon by modern manufacturing systems, our most potent encounters with 21st century materiality are experienced as massive, spontaneous material shifts of air, oceans and land that we recognize through the phenomena of 'climate change'. These colossal expanses of matter are dictating the conditions of our existence, for which we are compelled to design new technologies to gain purchase for our needs.

This relentlessly material and often fickle phenomenon in which 21st century global culture struggles to exist – may be characterized as Millennial Nature. Yet before it is possible to clearly define the terms of this phenomenon, Timothy Morton insists that we should divest our ideas of Nature of their entrenched aestheticisms since they obscure and constrain its true materiality. Yet, how do we - as Slavoj Žižek proposes (Zižek, 2010) – begin to embrace this material strangeness at a time in which we are witnessing continent sized toxic entanglements of plastics, wildlife and currents that constitute our Great Ocean Garbage Patches - which Jane Bennett observes are not only extremely lively (Bennett, 2010) but Timothy Morton (Morton, 2007) proposes they are also no longer entirely naturalized? Can we even begin to consider 'loving' these festering bodies as readily as Swampy might embrace a tree (Hollingshead, 2006)? Yet, not all of these bizarre encounters with Millennial Nature are shocking. When torrential rainfall burst the banks of the River Severn and water surged through the streets of Worcester this Christmas, graceful white birds paddled through the flooded town in a magnificent spectacle known as – Swangeddon (Edmonds, 2013). Millennial Nature has a unique kind of materiality that may be distinguished by its profound technological and social transformations that promise new design opportunities. While 20th century Nature has also been restlessly unpredictable, our design and engineering attitudes have generally sought protection from its effects - through the construction of barriers and powerful machines that have enabled us to believe that we can understand, control and therefore conquer matter. Yet, in the late 20th century researchers such as, Rachel Carson (Carson, 1962) and Edward O. Wilson (Wilson, 1984) showed these very processes that protect us and spawned the conglomerations of Le Corbusier's "*machines for living in*" (Marcus, 2000) – are also irreversibly destroying our environment. Global governments have responded with notions of 'sustainable development' where generations can meet their own needs without compromising the prosperity of subsequent generations. This commitment has intensified with the recent advent of megacities and with a global population set to hit 9 billion by the middle of this century (Parker, 2011), it has become clear that the survival of our species is deeply entangled with the future of the built environment.

Yet as we enter the Ecological Era, our technical apparatuses are out of kilter to our environmental systems, since they arise from an Industrial Age that attempts to correct or 'fix' these dynamic systems into a particular configuration. Take for example, the standardizations associated with building production with LEED and BREEAM (UK Green Building Company, no date), whereby mechanical building performance is linked to notions of environmental remediation. Such empirical pursuits do not deal with local variations of site, building or the use of a space and therefore impose unrealistic standards on the production of buildings that prioritise theory over practice. It is therefore our duty to elaborate a platform aiming at restoring, or at least adjusting the equilibrium between variably empowered actants into Millennial Nature and use ANT to help reconcile the deterministic, industrial worldview with the dynamic qualities of Millennial Nature. ANT offers the potential to generate the conditions for the production of a fabric that enables us to simultaneously design and engineer with objects, processes and environments that deal with the various agents of interest but re-integrate them in transformative ways. From the effectively inert bodies of machines, to the wilful agency of nonlinear systems and their variable performances within different contexts – ANT helps us find convergences and tipping points of transformation within the participating systems to allow us to produce qualitatively different kinds of outcomes. Perhaps, in a similar manner to Ulrich Beck's notion of a transition from First to Second Modernity, whereby established social territories (state, politics, society and culture) were dissolved to produce new inner qualities (Beck, 20000) - so ANT may facilitate a qualitative transformation of old dichotomies into new technological hybrids, new materialities and even novel kinds of technologised 'life'. Rather than setting to work by 'fixing' environmental changes through technological platforms alone, approaches that incorporate ANT as a conceptual and technical strategy may also seek cultural convergences with Millennial Nature. For example, in the city of Venice when walkways are flooded by the increasingly relentless high tides, or 'acqua alta' residents wear plastic bags over their clothes and walk along trestle tables instead of pavements. Such linking between ideas and platforms enables radical new approaches towards our perception of change – namely, while empirical measurements can be 're-normalized' or 'fixed' to achieve homogeneity, cultural adjustments seek diversification.

The entanglement of matter and information

Underpinning the complex behavior of General Systems Theory (von Bertalanffy, 1950) is the relationship between matter and information. This has been widely characterized in the behavioural and social sciences, such as Talcott Parsons proposed 'action theory' (Parsons, 1967) and Niklas Luhmann's exploration of communications on closed social-groupings (Luhmann, 1982).

Although a practice of cybernetics invokes an engagement with physiological processes, such as autopoiesis, these are usually imagined within closed systems that are insulated from real environments. When coupled with the idea that reality may be a giant computer program (Wolfram, 2002) the practice of cybernetics tends to privilege the abstract over the real. Consequently, from a design and engineering perspective it has become virtualized (Hayles, 1999). While this has led to the development of visualization software able to generate complex, evolving patterns such as, parametrics - identifying materials that embody these adaptive relationships has been more challenging. Indeed over the course of the 20th century matter became regarded as just another form of media (Pallister, 2014).

Yet, objects at relative equilibrium within a cybernetic system cannot undergo any kind of radical material transformation and thereby can only be read in terms of their capacity for pattern generation. For example, the Fluid Crystallization project by Skylar Tibbits and Arthur Olsen uses a tank of 350 neutrally buoyant spheres to investigate hierarchical and non-deterministic forms of self-assembly (Rosenfield, 2014). The orbs dock and break their transient connections within the liquid medium, like a 3D version of John Conway's Game of Life (Gardner, 1970). Although its pattern generating abilities appear abundant and represent a fascinating interface through which to observe the interplay between 'brute' matter and information, the system itself is unable to undergo any kind of radical material transformation. However, simply opening up the interactive loops in cybernetics and to make them even more complex is not in itself sufficient to evolve a radically different kind of technical system. For this to occur, the recoupling between matter and information is needed and can take place through a new materialism, which by engaging with ANT, directly speaks to Millennial Nature.

New materialism

21st century matter is very different to the brute, inert substances subject to a "*revolution operating on matter*" (Brown, 2002) that characterizes modern paradigms of thought. Rather, it is empowered and demands to be negotiated with. Material systems are not simply the consequence of relationships and networks of substances, such as those observed in cybernetic systems, but are chemically embodied (Latour, 2005). Indeed, our material encounters are shaped by complex chemical experiences that can only be partially observed through any lens of analysis such as, language, phenomenology and realism. Yet, following 30 years of advanced biotechnological development, the dynamic nature of matter is now much better understood at the molecular level and its chemical operations have been characterized in fine detail. Understanding biochemical processes within living systems creates a platform for a new materialist theory. It also offers a technical opportunity where a new kind of production system, which can meaningfully work with unpredictable planetary conditions, may be formed by coupling dynamic matter with systems theory and ANT.

Living technology

My background is in the biomedical sciences. I have a long-standing interest in the processes that may have shaped the origins of life – in other words, the way that inert systems and materials become lively. My work seeks a technical theory and principles of practice of 21st century matter to inform a design and engineering principles that can deal with a world in continual flux. Living systems possess a set of qualities that offer something potentially valuable to technical innovation in an age of climate change - in that they possess tactics that deal with constant change and uncertainty. In keeping with Timothy Morton's call for ecological forms of development that are not just another form of progressive modernism, the technologies of 'life' may offer a different kind of production platform that liberates technical innovation from machine-centred solutions. By applying the new materialism and agentised matter that has been proposed by Karen Barad (Barad, 2007), Jane Bennett (Bennett, 2010) and Graham Harman (Harman, 2010), a new technical platform that may share some of the properties of living things such as, movement, sensitivity and metabolism may be possible. By viewing agentised materials through the connecting framework of ANT, qualitatively different outcomes than industrialized 'wet' technologies such as the process of brewing can emerge that enable design to deal with:

• Environmental change.
• Persistence.
• Far from equilibrium states.
• Assemblages of heterogeneous bodies.
• Wetness.
• Lively materials.

To demonstrate a design philosophy that represents principles of practice of 21st century matter, nonhuman interests must be engaged so that materials themselves may directly influence the discourse and possibilities – perhaps even in surprising ways. My research has identified an experimental model through dissipative structures (Glansdorff and Prigogine, 1971) as a material platform, through which such conversations can be demonstrated and tested. Moreover, they are material paradoxes that link the classical and systems view of reality being simultaneously objects, which possess structure, yet they also embody material process. Their integrity is maintained by a continual flow of atoms that is set up across material fields and energy gradients, which eventually reach equilibrium.

Dissipative structures exhibit striking, lifelike properties which entangle "*space, event and movement*" (Tschumi, 2012) and self-assemble from basic ingredients. They also exert agency way beyond their structural field – imagine a storm-chaser observing a tornado and feeling the extensive winds that extend into the environment, long before the eye of the storm is ever reached. Dissipative structures possess unique technical characteristics with effects that extend beyond modern categories of form and function. For example, their multi scalar nature encapsulates Mark Morris' notion of "*miniature thinking*" where the collective organization of agents with qualities unique to their scale, can link the small and large worlds in a dynamic temporal relationships. This not only produces physical effects but also invokes the fantastic and uncanny – through scalar fantasy and alchemical lore (Morris, 2011). Applying ANT as a conceptual framework for exploration in combination with agentised matter may identify opportunities for technological innovation. Barad's notion of performativity as a discursive practice was used to examine the events within a series of over 300 laboratory Bütschli experiments. This approach aimed to bring to the forefront important technical questions that related not only to scientific phenomena but also cultural issues such as, ontology, materiality and agency, through discursive experimentation (Barad, 2007).

Dynamic droplets as living technology

The Bütschli system, which is formed by adding strong alkali to a field of olive oil, has been most extensively used in my research as a model dissipative system. It embodies key characteristics of matter at far from equilibrium states and can be seen with the naked eye (Armstrong and Hanczyc, 2013).

An experimental approach to the material realm empowers it to make its own arguments through transitional operations and networks of interactions. These are organized through the actions of assemblages, whose dynamic actions shape our experience of the world. I chose a dissipative structure in the form of a simple dynamic droplet system to frame my material arguments. Zoologist Otto Bütschli first observed the phenomenon in 1892, when he added a drop of strongly alkaline potash to olive oil (Bütschli, 1892). He noted the spontaneous emergence of dynamic structures that he likened to a 'protist', which is a kind of single celled animal, like an amoeba. Bütschli was interested in countering the claims of vitalists by demonstrating simply chemical principles could underpin complex biological phenomena and captured his observations as a series of drawings. Yet, this simple soap-making recipe was not examined with modern laboratory equipment until it was recreated using 3M sodium hydroxide and Monini Olive oil (Armstrong and Hanczyc, 2013). On addition to the olive oil, the strongly alkaline droplets quickly broke up into organizing fronts of activity and a collection of centrally placed droplets that were about a centimeter in diameter. The droplets were inexpensive to produce, could be readily viewed at the human scale. They demonstrated lifelike emergent properties and offered a model system for observing complex material relations over short time scales, which lasted from milliseconds, up to an hour. Observing the droplets at low power (x4) magnification, using a light microscope, a range of striking lifelike phenomena were observed such as, movement, group interactions, the production of structures and environmental sensitivity. Such complex activities appeared to emerge from a set of simple operations conferred by the metabolism of the system in converting oil and alkali into ‘soap’, which provides the energy for the droplets that absorb energy from their surroundings (endothermic) as well as providing the basic material transformation. Butschli droplets are performative and provide a set of testable outcomes, as morphologies and behaviours, which relate to the spontaneous creativity in the system. Bütschli droplets can move around their environment, sense it, and even produce products in parallel forms of organization and without a hierarchy of order. These spontaneous groupings form assemblages by making loose, reversible interactions between each other and generate the flexibility, robustness and environmental sensitivity of the system.

As the droplets evolve over the course of many minutes within the oil field, they form a microcosm of manifolds, whose undulating interfaces imply the possibility of countless worlds nested at many scales within each other. The droplets possess a unique set of aesthetics that are not fixed but are continually transforming themselves and their environment by creating the conditions in which further populations of droplets could act and be guided through the space. This system provided a unique environment where far from equilibrium systems could be observed, which relentlessly spin a range of interfaces whose chemical interactions form networks that fabricate worlds – like tiny 3D printers. While the dynamic events can just be seen with the naked eye, through a low powered microscope observers are offered a new lens on reality - or a form of chemical visualization software. Within the undulating field lifelike patterns can be seen that are quite unlike the inert matter that underpins modern paradigms, from which stable objects are forged such as, tabletops, buildings and machines.

Perhaps surprisingly, the behaviour of assemblages is rather conservative and predictable although these groupings operate within ‘limits’ of possibility. This can be likened to making a cake. When sugar, flour, butter and eggs are mixed together and put into an oven at a particular temperature a spectrum of outcomes is likely, ranging from a dirty black biscuit - to a delicious gâteau. The same is true for the Bütschli system, which also has a predictable range of behaviours. The exception to this rule is when the assemblage reaches a tipping point, where group interactions also give rise to novel, emergent, complex events that are not characteristic behaviours of any of the participating agents but yet are striking and recognizable. Occasionally, a range of different phase change in the internal condition of active Bütschli droplets takes place that may occur at the level of individual droplets or within populations. An individual droplet phase change may be observed during the ‘werewolf’ moment. Although the exact events that bring about the transition have not been fully characterized, it appears that when a droplet reaches a critical stage in the amount of surface area it presents for chemical reactions and the mass of the body, crystalline deposits are rapidly deposited at the interface. At first, this increased precipitation occurs away from the direction of travel, which creates the illusion that the droplet is growing a furry tail. This precipitation alters the centre of gravity of the droplet, which begins to move erratically as the mass and drag of the crystals begins to alter its movement through the medium. This stage of agitation is quickly followed by complete occlusion of the droplet interface with crystalline deposits, so that it appears to be completely ‘hairy’ yet inert. The entire sequence of events consistently precedes quiescence. Other kinds of recognizable behaviours are observed in the genesis of the Bütschli system. For example, population scale changes in behaviour and morphology may be observed where droplet assemblages suddenly change shape and move away from each other. How such tipping points works is not understood, but the transformation in the system is likely to be the result of multiple, synchronous ‘werewolf’-like events that culminate in an irreversible state.

Natural computing

Natural computing is term and an emerging scientific practice that was inspired by Alan Turing’s interest in the computational properties of natural systems and exists as an overlapping set of practices that span from modeling biological systems to looking at the performance of dynamic materials (Denning, 2007). However, the term natural computing is very broad and relatively recently established, so its application has been developed and interpreted according to the aims of the various participating research groups from a range of overlapping scientific research practices that include artificial life, complexity chemistry, synthetic biology, biomimicry and genetic algorithms. Researchers include Martin Hanczyc at the University of Trento (Hanczyc et al, 2007), Lee Cronin, at the University of Glasgow (Cronin at al, 2006), Klaus-Peter Zauner at the University of Southampton (Palmer, 2010), Gabriel Villar at the University of Oxford (Villar, Graham and Bayley, 2013), and Andy Adamatzky at the University of West England (Adamatzky et al, 2007). The main goal of natural computing is to develop programmable, lifelike systems using a spectrum of platforms to better understand and reflect the properties of living things such as, adaptation, learning, evolution and growth.

Fundamentally, the field of natural computing is inspired by the capabilities of natural phenomena and the operations of lifelike systems. These exist at far from equilibrium states and therefore spontaneously possess abundant energy, which empowers them to act without human instruction to seek rich material connections that issue the substances of life that constitute the operating system for natural computation. Such ‘assemblages’ (Bennett, 2010, p23) embody the principles of ANT by coupling chemical information and substances through empowered material bodies to generate new relationships and outputs through an open system of material connections that may ultimately transform the system itself.

Natural computing techniques can therefore be applied to shape the outputs of the droplet ‘hardware’ of Bütschli droplets through chemical programming, or ‘software’, which ‘converses’ with the droplets through the assemblages that constitute their soap-producing metabolism. Natural computing does not use top-down instructive programming such as, genetic codes, but orchestrates the creative agency of matter through soft control systems that encourage horizontal coupling between chemical bodies, to open up new design and engineering possibilities. For an assemblage-forming system to be experimentally useful, it must be possible to shape its operations. From a technical perspective, assemblages may be regarded as leaky, flexible groupings of materials that form the operating system of natural computers, which deal with the computational properties of matter. Natural computing (Denning 2007) operates at the level of molecular interaction but can also manipulate the complex outputs of living technologies at the human scale as a meta-technology, which can horizontally couple actants together – across heterogeneous groupings to form new tools and technical objects. For example, internal conditions in the Bütschli system can be manipulated by adding a soluble mineral to a droplet to produce solid matter, or precipitate, in the presence of carbon dioxide. Additionally, introducing chemistries into the external environment such as, organic solvents like alcohol, into the olive oil medium reduce surface tension and cause a rapid mass movement of droplets towards the source. Yet, for natural computing to have cultural relevance the systems must exist at a scale by which they can be observed, manipulated and inhabited.

Through a series of design-led experiments, which explored the possibilities of programming the Bütschli system using simple chemical programs, it was possible to demonstrate that assemblage technology could be applied to address specific design challenges such as, ‘fixing’ carbon dioxide from solution. Despite the material simplicity of the systems, the outputs are highly complex.

Hylozoic Ground installation: Scaling up living technology

Philip Beesley invited me to produce a range of design-led experiments to form a series of chemical 'organs' within his cybernetic installation, the 'Hylozoic Ground' that was exhibited at the 2010 Venice Architecture Biennale (Armstrong and Beesley, 2011). These were imagined as an evolving experimental platform to complement Beesley's architectural agendas that spoke of fertile terrains and provoked the possibility of living systems emerging within a cybernetic matrix over the 3-month duration of the exhibition. A range of chemical programs, such as modified dynamic droplets and Liesegang rings (Liesegang, 1869) were designed that could respond to these ideas by choreographing connections between natural and artificial systems. Each chemical organ system had a unique identity that variably responded to the spontaneous material exchanges carried by the flow of air, water, light and heat through the gallery space. Transformations through the simple metabolisms notionally suggested that – with enough time - new kinds of Nature might eventually be produced within the installation space. These multiple exchanges constituted a primitive physiology that is spatially distributed through brightly coloured bodies, polished flasks and activated gels. Gradually their presence becomes naturalized and their visibility receded into the dark, primordial material matrix of the installation space where these proto-ecologies undergo evolutionary change as they respond, interact and adapt to their constantly changing environment. Yet Nature is not neutral and deeply contextualizes which specific life forms may persist within a system. Over the duration of the installation, it was evident that the original Hylozoic Ground chemistries were no more than transitional objects, which with the passage of time their identities became increasingly ambiguous. Within the open gallery space, some of the chemical bodies persisted, others completely transformed and many withered.

Peter Sloterdijk proposes that such leaky spaces are patrolled by a kind of immunology where objects can move from one ontological sphere to another – a process that is facilitated by anthropotechnics (Sloterdijk and Hoban, 2011). Yet in a nonhuman world, boundary interactions are not exclusive to the behaviour of discrete object populations such as, flocks of migrating birds, schools of dolphins, or dynamic droplet assemblages, but also exist within complex assemblages on massive scales, such as hyperobjects that include soils and atmospheric dust clouds (Morton, 2012), as well as at the molecular level through strong and weak forces between objects including gravity, electromagnetism, strong and weak nuclear forces. These produce a host of interactions including, attractions, repulsions, amplifications and extinctions which may be observed at the interface of trembling dynamic droplets and migrating reaction-diffusion bands. Through the theory and practice of ANT these, assemblages could be understood and designed as overlapping with and being infused by the medium in which they exist and read through natural computing as events, for example, the production of brightly coloured carbonate shells on exposure to carbon dioxide.

Future Venice: Sustainability through living technology

When assemblage technologies are applied in an architectural context, they can produce different kinds of outcomes to that of machines, such as proposed by the Moses project – a series of 78 mechanical gates being constructed in the lagoon to literally hold back the tide like a giant, robotic King Kanut (The United Nations Office for Disaster Risk Reduction, 2013). An urban-scale assemblage technology is being explored in Future Venice as a way of identifying alternative solutions to machines in ways that address ecological challenges.

Future Venice proposes to grow an artificial limestone reef under the city using a giant natural computer that consists of droplets similar to the ones that we've just seen. Droplets are designed to move away from the light and use dissolved minerals and carbon dioxide when at rest, to produce a kind of 'biocrete'. The system would be titrated to need by adding droplets to the light soaked waterways of the city that move towards the darkened foundations that stand of narrow wood piles. This is a bit like the city standing in stiletto heels on the soft delta soil on which it's been founded. Here they would produce a biocrete accretion technology that would spread the weight of the city over a much broader base – and put platform boots on Venice. Of note, the marine organisms in the waterways already produce a kind of biocrete and it is anticipated that the natural computer will work with the marine animals to co-construct an architecture that is meaningful to both the creatures of the lagoon as well as the city inhabitants.

Should the environmental conditions of Venice change and the city dry out rather than drowns as currently predicted - then the natural computer could change the range of its outputs. Rather than growing sideways to spread the minerals over a broad base, the accretion-producing droplets deposit their material on the woodpiles, sealing them from the air and stopping them from rotting.

Venice is an ideal site for exploring the potential of natural computers as an architectural technology, since the watery foundations create the conditions in which matter can move and flow around the site. Indeed, the importance of infrastructure cannot be overstated for the dynamic functioning of assemblage technology, which is supported and enabled by the provision of elemental infrastructures – namely, water, air, heat and soil. These offer a flow of resources, enable movement, provide supportive physical forces and remove waste and inhibitory products from the local environment. The possibility of dynamic matter within an architectural system potentially changes the goals of a building that may now catalyse the continual flow of materials through a site, which increases its environmental fertility. In other words, buildings may become life promoting, not just for humans, but also for entire local ecologies.

Persephone: Planetary operations and living technology

By considering natural computing approaches on a much lager scale, it is possible to extend principles of technical development through living technology and ANT networks to propose the design of an entire ecosystem. Jordan Geiger proposes the dynamic physical systems, such as surface tension embody the sites of Very Large Organizations (VLOs), a term that refers to contemporary institutional assemblages where "*the built environments of work, public assembly, agriculture, incarceration, trade, travel, education, and even death are increasingly part of global financial and communications networks*"(Geiger, 2012, p134). Likewise, Persephone may be regarded as a VLO, being part of the Icarus Interstellar group's work on the development of a starship to be constructed in Earth's orbit within 100 years. It is a project that started in 2012, which embodies an evolving, architectural-scale, process-led construction platform that operates as a primordial ecosystem for a worldship, which could evolve alongside the crew. The living interior of the worldship is a synthetic ecology whose operating system is a programmable fabric that will be constructed from basic chemical ingredients, which are realized through natural computing techniques and the assemblage-based technology of soils. Indeed, soil is an ancient technology that inserts space and time into chemical reactions and thereby delays the heterogeneous matter in the worldship from reaching equilibrium. It also increases the surface areas available for exchange and the flow of materials to maintain a dynamic fabric. As Persephone is at its earliest stages of development its living fabric is being prototyped as laboratory experiments that explore the performance of activated gels. Under the influence of gravity, brightly coloured salts can be seen forming and dissolving as they move through the gel matrix as periodically forming bands. Combined with hydroponics and micro agricultures, these assemblages propose to generate a life-supporting matrix on which tertiary structures may be constructed for human habitation. Persephone challenges the current conventions of technology not only in not being made of inert materials but also by using language that is derived from process philosophy to shape the expectations of the system. The processes themselves are based on the flow of elemental infrastructures (air, water, plasma, heat and earth) that enable exchange between varieties of heterogeneous materials by inserting time and space into the post-natural fabric of the worldship. In turn, these are further perturbed by a variety of agents. Within this intense field of activity, the networks, relationships and flows established by the material computer move the system away from equilibrium and towards dynamic states that create the preconditions for the occurrence of lifelike events. Yet, Persephone's technical system does not seek to create lifelike events themselves, but to increase the probability of their occurrence. Consequently, Persephone's design details are not predetermined but are probabilistic and respond to perturbations within the worldship. Indeed, they may even change and evolve in environmentally sensitive ways over time. These non-terrestrial material networks of flows, exchanges and transformations may even produce new species of lifelike materials that are categorized not according to their differences, as in classical Linnaean taxonomies, but are grouped according to their similarities and connections through oceanic ontologies. In this way Persephone's technological fabric produces commonalities between the diverse, heterogeneous agents that actively codesign the living interior to the worldship. Persephone's programmes, therefore, operate to prolong the diverse interactions that may give rise to synthetic structures that are, ultimately, indistinguishable from 'life' itself. Such life-promoting infrastructures are essential for the colonization of non-terrestrial environments and for the propagation of life throughout the cosmos.

The importance of infrastructures in the performance of living technology

Elemental infrastructures are essential to the environmental performance of assemblage technology. They are enablers, which allow the flow of matter to take place and provide the local context for the interactions between non-equilibrium systems that confer architectures with lifelike qualities. For example, Henk Jonkers' self-healing concrete uses extremophile bioprocesses to extract carbon dioxide from their surroundings. The microbes are activated by water moving into microfractures and use dissolved carbon dioxide to produce tiny crystals to seal the cracks at their earliest stages of formation (Jonkers, 2007). Yet without access to a fluid medium in which bacteria and carbon dioxide can freely inert, the potential actants in the self-healing concrete system remain inert, like spores, waiting for the right conditions to unleash their creative potential.

Yet modern technical systems require mechanical infrastructures, such as optical fibres, electrical cables and Wi-Fi networks, so our living spaces are poorly supplied with elemental infrastructural design. For example, our kitchens and bathrooms are designed as drains, not circulatory systems. Airflow is also equally unsophisticated in being directed through spaces like vents, rather than as a breathing system that optimizes the potential for exchange. So the very conditions in which assemblage based technologies may bloom are currently restricted as they are housed within environments that are rich in mechanical infrastructures, not elemental ones.

However, with the appropriate elemental infrastructure, new kinds of technical systems may thrive to build new networks of chemical interactions within a space, which could be regarded as metabolic functions. For example, rather than being conceived of as 'machines for living in', buildings – which are concentrated sites of technological activity - could be designed with infrastructures that nurture architectural 'organs'. Architectural organ systems are likely to be aquariums that contain microcellular organisms such as, bacteria and algae, or even smart chemistries, like dynamic droplets that perform equivalent work to machines, such as, producing heat, filtering water or fixing carbon dioxide. By feeding the metabolic processes within these tanks with 'food' or nutrients, such as carbon dioxide, organic waste or grey water, the many bioprocesses within these micro agricultures would be free to process and exchange matter. Yet, architectural organs do not need to be designed as open compost heaps, they could be engineered in ways that render them invisible to residents by situating them in under-imagined sites within our buildings such as, under floors. However, architectural organs could also be highly visible and exist as fetishized objects such as, in Phillips Microbial home (McGuirk, 2011) – where voluptuously shaped bio processors transform waste products into useful substances that exchanged and transformed through a locally defined ecology. Strategically positioned, these architectural organs may give rise to buildings with physiologies that strengthen the material exchanges within a community through networks of metabolic processes and act as biotic, life promoting oases for human and nonhuman communities.

Arup, who are exploring the benefits of facades as the site of algae production for the International Building Association in Hamburg, is already developing the idea of microorganisms powering our buildings in many ways. These take the form of aquariums full of microalgae that are fed by sunlight within tall, narrow façade panels through which carbon dioxide is bubbled. The microorganisms flourish and grow and their biomass is syphoned off, dried and combusted to offset energy consumption within the building (Steadman, 2013). Other prototype projects further explore the possibilities of bioprocess technical systems that operate through open assemblage platforms. Artist Anne Brodie and microbiologist Simon Park have developed a system for using bacterial light, called bioluminescence, to illuminate building interiors. This kind of light is produced by a range of microorganisms and is activated by shaking. The mood elevating light could therefore be activated by the footsteps of passers by, or by the vibration of traffic, which could reduce the dependence of roads, footpaths and even bridges off central energy grids. Moreover, with the power of synthetic biology to modify natural organisms and splice genes into their cellular operating systems that enable them to produce bioluminescent proteins, even ordinary organisms may be able to contribute to a future in which light is produced by biological systems, as suggested in Alberto Estevez's 'Genetic Barcelona' that proposes that the streets of near-future cities will be lit by genetically modified trees (Myers and Antonelli, 2012, p.68-69). Indeed, chemical and biological assemblages may even be increasingly used in the production of traditional architectural materials by growing them such as, Philip Ross' furniture produced by fungal roots (Ross, 2013) and Ginger Krieg Dosier's 'Bio-bricks', which are made from bacterially fused sand particles (Myers and Antonelli, 2012, p.113). In the near future these materials will be used on a larger scale and will double up as both material and technology taking the form of living construction systems such as, Magnus Larsson's project 'Dune', which is a giant bacterial printer that reverses desertification by traveling through the desert, creating solid ground for the settlement of plants and other organisms to produce soils (Myers and Antonelli, 2012, p62-65) – which are the beginning of all biodiversity. Gradually, our machines for living in may become sites for many different species of assemblage technology and the infrastructures that nurture them may be distributed throughout our homes. These entanglements of matter, technology and elemental fabrics may be thought of as buildings 'organs' that could perform a diverse range of useful work that do not decrease the fertility of our environments, but could enhance them by using bioprocesses to transform matter into lighting, soils, and foodstuffs, which keep our cities fertile.

Combined technologies

Yet, the performance of assemblage technologies does not have to be constrained by the limits of its own platform, but also extended by combing its operations with other technological platforms such as 3D printing, which can further increase the possibility of developing radically new techniques and technologies that may take on a range of different appearances from something as mundane as a set of chambers in which reactive chemistries can explore new, complex configurations, to wholly synthetic environments.

In the multidisciplinary WET Fab event held at the Cronin Lab in Glasgow, and funded by the Engineering and Physical Sciences Research Council (EPSRC) designers, computer scientists, engineers, physicists and chemists explored the Fab@Home platform together to "*produce some new science*" (WETFab, 2011). During the two-day event dynamic chemistries were spatially positioned using a Fab@Home printer. While the tests from the workshop were exploratory, introducing inorganic salts into gels and oils, the Cronin group went on to develop a prototype system that could sequentially build complex chemistries (Symes et al, 2012). The chemical 'reactionware' and the reagents themselves were made using the printer. The reactionware itself was fabricated using bathroom sealant to create a series of reaction chambers with precisely specified dimensions, which were connected with tubes of different lengths and diameters. Once the container system was developed, then a range of different chemistries could then printed into the chambers to create a reaction sequence that produced increasingly complex molecules. The WETFab system therefore combines the notion of a reactor with a reaction in that the printer not only orchestrates the chemical sequences but also shapes the environment in which they take which is a qualitatively different approach to the neutral environments in which chemistry is usually conducted. Future developments may explore printing catalysts into the wall of the reaction chambers, or even ultimately create complex biological simulations using printed tissue cultures to simulate chemical reactions taking place within the body. Indeed, this reactionware model could transform the process of drug discovery and testing by being able to quickly and cost-effectively screen the effects of new molecular combinations. Should the platform be productized as a miniature laboratory where inkjet cartridges may be supplied with different chemistries and software so that the printer can fabricate the right containers and chemical sequences then the system forms a portable laboratory that could greatly increase access to medicines and the ability to manufacture new formulations. Indeed, WETFab changes the authorship of the reactions where the chemistries themselves possess agency within differentiated environments and therefore directly contribute to the innovation process (Adams, 2012).

ANT and innovation

While ANT has created access for culturally adopted technologies to access the complex web of relationships in different actor-worlds and their dynamics, to date there has not been a technical platform that can fully navigate these opportunities and open the ‘black boxes’ of innovations and technology developments through open, networked developments. While the Internet and graphical representations can depict the way these technologies may appear, they are merely aesthetic representations and are not technically operationalized. Digital computing relies on mechanical devices to enact systems of embodiment and therefore is always constrained by the resource consuming, object-centred, industrial paradigms. If we are to overcome the ‘backward looking’ perspective of ‘standard stories’ of modern science and technology that extrapolate from documented events to generate frameworks for the future, then it is essential to imagine and fully explore alternative modes of population. Agentised matter, when coupled with ANT and orchestrated through natural computing has the potential to create the conditions for a new production platform that could potentially change our current consumptive practices into ones of synthesis whereby humans are co-authors of their living spaces. While there are few precedents for assemblage technology – most of them originate from 19th century origins of life experiments in the work of ‘gentlemen’ scientists such as, Ferdinand Runge (Runge, 1850), Moritz Traube (Traube, 1867) and Otto Bütschli (Bütschli, 1892) – nonetheless the practices that wield the technology are actually ancient such as gardening and agriculture. The outcomes of these practices are probabilistic and engage with forms of soft control so that artisans understand that there are a spectrum of possibilities that may be produced by their context and even the skill of the practitioner – a principle of alchemy. In designing such experiments it was therefore necessary to use speculative methods since there are many uncertainties working with the technology, which is emerging and incompletely characterized. Yet, by making themselves more familiar with the system through regular engagement, practitioners have increasingly more influence over the outcomes. Indeed, the outputs of assemblage technology require familiarity through which they may be coerced and persuaded, rather than commanded. Their outputs are therefore probabilistic, resist traditional classification systems and may even be regarded as producing Latour’s notion of ‘post-epistemological’ phenomena (Latour, 2013). Assemblage technology is at the earliest stages of its development and promises to be a powerful integrating platform that increases our choices – rather than proposes totalizing solutions. This requires a different approach to design challenges since humans become codesigners, not sole authors in these creative, materially empowered collaborations.

The application of the conceptual apparatus of ANT in the rapidly developing areas of new technologies can be evaluated through the emergence of projects and prototypes that explore the possibilities for innovation. However, these potential new platforms are still emerging and there is little, if any empirical data to quantify its effects. While there is promise for their capacity to generate more sustainable solutions than mechanical operating systems, their effects are yet to be demonstrated. There is particular excitement regarding the possibilities of 3D printing and its potential to bring about a new era in making. Yet, to date – except for several very expensive tissue-culture protoypes – the mainstay of this technology has been to squirt out low-grade plastic objects that exist within a consumptive, non-environmental paradigm (Armstrong, 2014). However, laboratory experiments are uncovering radical new areas for innovation and technological development including the development of a whole new field of computing, through which ANT may be further explored and developed.

Despite the challenges posed by emerging technological platforms, such as natural computing, valuable insights may be provided into the nature of materiality in the 21st century that are potent enough to consider what a pertinent technical theory and principles of practice for 21st century matter might be. Of particular interest are the opportunities in which technological systems may engage with the unpredictable character of Millennial Nature. Multi disciplinary explorations appear to be most promising in provoking new opportunities for a range of technical innovations, such as by harnessing the spontaneous lively and technological properties of the material realm, which may be applied for example, in the production of spatial programs that are embodied through the production of post natural fabrics and synthetic ecologies.

Yet, the outputs of assemblage technologies are not static edifices but maintain their liveliness through metabolic processes, so they may continue to couple with others actants, bodies and networks of material flows, to transform their surroundings, rather than consume them. They are therefore are consistent with Morton's notion of an 'ecological' practice (Morton, 2007), where we learn how it is possible to design with metabolic processes in ways that do not try to mimic tactics that are native to mechanical systems. Yet, natural computing and living technology do not propose to save us from the contrary predicament of Millennial Nature, which is continually constructing surprising new material encounters. Rather, they may simply increase the portfolio of technical strategies through which we may (re)negotiate our own ecological survival.

Yet, from an idealistic viewpoint, assemblage technology, operating through ANT and living technology proposes to completely change the developmental platform that underpins this millennial wave of human expansion. This new 'living' platform utterly rejects the austere view of sustainability and looks to the technologies of life as its allies, to sever our mechanical umbilical cord so we can make a transition towards an ecological existence that does not conserve resources, but promotes 'life'. Indeed, assemblage technology something potentially revolutionary to our existing design and engineering methods by liberating the radical creativity of the material realm and catalyzing many different kinds of couplings with Millennial Nature. These potent hybrid bodies may continue to combine with others in ways that transform, rather than consume our surroundings. Of course, humans may play a part in these manifold metamorphoses by unleashing the shocking fertility of the material realm through the production of vibrant architectures. In this way, we may resist the relentless march of industrial machines that are unrepentantly reverse-terraforming the Earth.

At this critical juncture in our existence, we cannot accept the glut of economic taboos, political inertia, conceptual blind spots and social platitudes that prevent us from rewriting our shared future as one of mutual survival. Instead we must urgently seize this moment and produce vibrant architectures to prompt an immediate (re)imagining of our world, notions of life, community and what it means to be human at a time of ecological crisis – so that we can set free the creative powers of our partners in (co)existence and facilitate their inexorable evolution.

Living technology therefore heralds a new technological era - the age of Millennial Nature – that is underwritten by ANT and wielded through natural computing, to catalyze the production of post natural fabrics and bring forth ecological paradigms to shape a range of forward-looking new futures and innovate through open collaborative networks that have no need for a rear-view mirror.

Values

Since the application of emerging technical systems, social interactions and material practices are forged by evolving knots of internal external and material relations, they also reflect and shape our values. In other words, in an Ecological Era, the outcomes of innovation cannot be encapsulated by a simple set of formal rules whereby input is compared with output – even calculus doesn't cut it - but rather ANT in the process of innovation demands to be evaluated by virtue of its robustness, creativity and other evolutionary characteristics – which can reflect and respond to the changing needs, of society and ecology – where designers and the public are actively engaged in the editing process – through which more 'local' issues of taste, history and societal influences are expressed.

But how do we respond to the speed and variability of all this technological innovation and potential an Ecological Era without losing our bearings on some meaningful sense of culture?

This conundrum raises the issue of value creation, which owing to its evolutionary characteristics resists the classical discourses associated with Platonic notions such as, beauty, which prioritizes the visual realm.

[insert Barbican essay].

And it does not mean that the Industrial Age is set for a rapid or even total decline. It will take generations to build up a new conceptual, material, technological and manufacturing portfolio that can replace, or even hybridize with our industrial platforms so that they have a different kind of impact on our dynamic reality (other than resource depletion). In the meantime we can better navigate the decisions that we make, resolve aspects of confusion or conflict that arise from these clashes in paradigms – e.g. renewables harness the dynamic properties of Nature through fundamentally industrial structures – compare a solar panel that can only produce electricity from sunlight, with the multiple parallel outputs that can arise from growing a tree – and open up new innovation spaces where we can mix and match to suit the fundamental questions and challenges that we are currently facing.

Access to the technical system that will define the Ecological Era will not 'solve' all he problems we face. Indeed, it is lively to bring new challenges that we have not previously encountered. However, the most positive steps that understanding the simplicity underpinning our widespread consternation and the multiplicity of explanations that we give ourselves is – that we are expanding our technical platforms as a species is that we can make new choices about the way that we operate within the world and decide where our responsibilities are placed and how we implement them.

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